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THE TRANSMUTATION OF MERCURY INTO GOLD

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In March 1924, Prof. Hantaro Nagaoka et al. (Tokyo Imperial University) described their studies "on the isotopes of mercury and bismuth revealed in the satellites of their spectral lines"—gold in particular. In May 1925, they reported some of the technical details.

Nagaoka and his co-workers discharged about 15 x 104 volts/cm for four hours between tungsten and mercury terminals under a dielectric layer of paraffin oil. They used the Purple of Cassius test to detect Au in the viscous residue of C, Hg, etc. The black mass was purified *in vacuo*, then by combustion with oxygen and extraction with HCl, to yield Au, either in aqua regia solution or as ruby-red spots in the glassware. Microscopic films of Au were found on occasion.

Nagaoka stated that when a discharge was passed through drops of Hg falling between iron electrodes, the formation of silver and other elements was observed. Another run of an Hg lamp for more than 200 hours at 226 volts produced a milligram of gold plus some platinum. It was noted that: "In order to be sure of transmutation, repeated purification of Hg by distilling in vacuum at temperatures below 200°C is essential."

Considerations of the satellites of the spectral lines of Hg led Nagaoka to the conclusion that a proton is "slightly detached" from the nucleus of Hg, and it can be removed. It was surmised that "if the above assumption as to the Hg nucleus is valid, we can perhaps realise the dream of alchemists by striking out a hydrogen proton from the nucleus by α-rays or by some other powerful methods of disruption" to produce Au from Hg.

At about the same time, Professor Adolf Miethe of the Photochemical Department at the Berlin Technical High School found that the mercury vapour lamps, used as a source for ultraviolet rays, ceased to work after a time because of a sooty deposit which formed in the quartz tubes. Miethe tested these deposits and detected gold. Subsequently, Dr Miethe and Dr Hans Stammreich were issued German Patent Specification No. 233,715 (8 May 1924) for "Improvements in or Relating to the Extraction of Precious Metals".

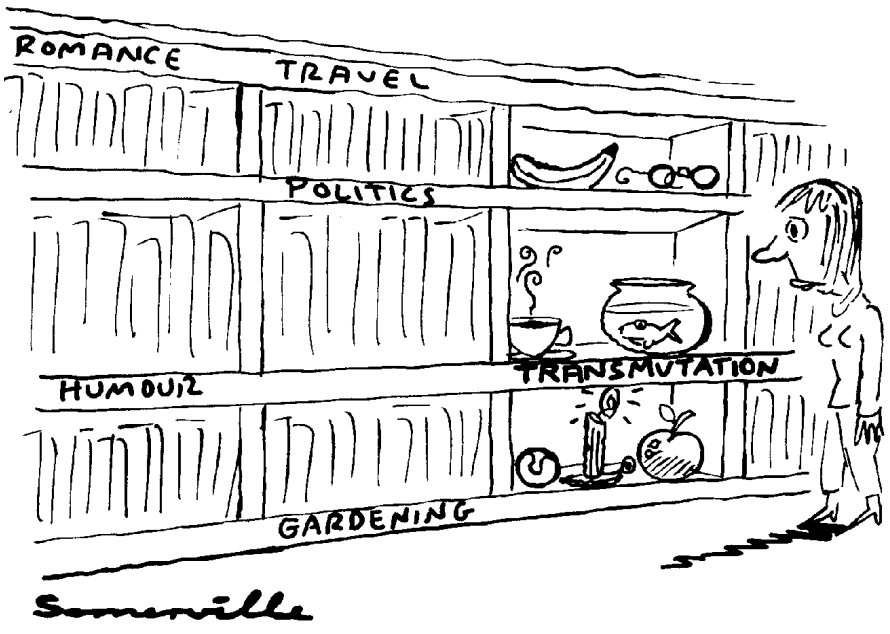
According to the specification: "...an electric arc is formed between mercury poles, in the same way as is done in mercury quartz lamps. With sufficient difference in potential, gold is then produced in the mercury. It is advisable to condense again the evaporated mercury. The quantity of gold produced depends, all other conditions being equal, on the quantity of current and also, among others, on the vapour pressure of the mercury or on the difference of potential in the arc. The difference of potential in the arc must therefore be sufficiently great. If it drops to excessively small amounts, the efficiency will be greatly reduced. If the difference of potential is increased, the quantity of gold formed will be considerably increased, beginning with a certain difference of potential."

In July of 1924, Dr Miethe announced that he and Dr Stammreich had changed mercury into gold in a high-tension mercury vapour lamp. The experiment produced one dollar's worth of gold at a cost of US$60,000, equivalent to over $2 million today (gold then sold for $330/lb).

Miethe used a potential of 170 volts applied for 20–200 hours. The lamp consumed 400–2,000 watts. A minimum potential difference is necessary. The yield of gold was minute: 0.1–0.01 mg. The mercury and the electrodes were analysed and determined to be free of gold before the experiments. Miethe was not able to attempt to prove the production of α-rays or β-rays, hydrogen or helium.

O. Honigschmid and E. Zintl determined the atomic weight of Miethe's mercuric Au, using potentiometric titration of auric salt with $TiCl_2$. It was found to be 197.26 (± 0.2), which is heavier than ordinary Au (197.2). They emphasised the need for a mass spectral analysis.

Frederick Soddy responded to the announcement of Miethe's claims with the suggestion that such a change might be effected by attaching an electron to the mercury nucleus: "Consider the collision of high-speed electrons with mercury atoms. A small proportion of these electrons must be directed upon the



nucleus. If they possess sufficient energy to penetrate the external levels of electrons in the mercury atom, they must reach the positively charged nucleus and be captured by it. Since the loss of an electron (as a β-ray) by the nucleus of an element results in the atomic number of the element in question being increased by one, the gain of an electron by an atomic nucleus must result in the diminution of the atomic number by one. This is quite general. In the case of an isotope of mercury of atomic number 80, the product will be an isotope of gold of atomic number 79.

"Upon existing knowledge it is simply a question of (1) the potential sufficient to drive the electron through the outer levels of electrons surrounding the mercury nucleus until it comes within the sphere of attraction of the powerfully charged nucleus; (2) whether the exceedingly small fraction of direct collisions with the nucleus that is to be anticipated will be sufficient to enable the gold produced to be detected.

"As regards the first, it may be expected that the repulsion of the external shell of mercury electrons will diminish rather than prevent altogether the chance of the radiant electron reaching the nucleus; for once the shell is penetrated, the resultant force on the radiant electron must be on the average an attraction... The chemical detection of the gold produced would probably be the more formidable experimental difficulty."

In the opinion of A. S. Russell: "The experiments on the transformation of Hg into Au suggest the possibility of the transformation of a nucleus into that of the element next below it, by the absorption of one electron when both nuclei are stable. This occurs most obviously as an isobar. The possibility of the existence of two isobars of odd mass-number, Tl 205 and Au 199, among non-radioactive elements may be inferred from experimental work... Aston has shown the existence of the Hg isotope 199... This type of transformation may occur in the two pairs of elements Pb and Tl, Hg and Au... The masses of the Tl and Au produced are 205 and 199 respectively."

Aston advanced strong arguments against the probability of the alleged Hg-Au transmutation. Conceivably it could be effected by the addition of an electron to the nucleus of Hg or by removing a proton from it, but the chance of an electron hitting a nucleus is extremely remote, and its weight would not make a significant contribution. Theoretically, an Hg isotope of atomic weight 197 could absorb an electron and produce common Au, but none of the six Hg isotopes (198, 199, 201, 202, 204, 209) identified by Aston has that weight. According to Aston, the removal of a proton from the nucleus by Miethe's method is untenable: "The forces employed are ludicrously inadequate."

The process can be shown as:

Hg – α – θ	= Au
At. wt. 201 – 4	= 197
80 – 2 + 1	= 79, or:
Hg – 4H – 3θ	= Au
At. wt. 201 – 4	= 197
80 – 4 + 3	= 79

In December 1924, the journal *Scientific American* announced that it was arranging for a comprehensive and exact test of the Miethe experiment. The test was conducted at the Department of Physics, New York University, by Professor H. H. Sheldon and Roger Estey. They used a quartz lamp which contained no gold, and pure tungsten wires were sealed into the quartz to provide electrical contacts. The mercury was tested for purity. Three runs were made, lasting from 30–50 hours each, at about 170 volts/13 amperes. The mercury was removed and tested.

"In no instance was any trace of gold detected... According to Prof. Miethe's reports, taken in connection with the theoretical interpretation of Prof. Soddy, this experiment should have produced a substantial quantity of gold; at least ten times as much as could easily have been detected by the analytical methods used. The negative result of the three experiments established, therefore, a strong probability that the transmutation announced by Prof. Miethe could not be confirmed."

The researchers procured from the manufacturers in Germany a replica of the lamp used by Miethe, and repeated the exact technique described by him. The final run lasted 172 hours, at 165–174 volts/12 amps, depending upon the temperature of the lamp:

"After the run, the most careful analytical tests failed to show any trace whatsoever of the precious metal.

"It is necessary to conclude, therefore, that the experiment described by Prof. Miethe does not always result in the transmutation of mercury atoms into gold atoms. The experiments recorded by Prof. Miethe and our own experiments, conducted as far as humanly possible in exactly the method described by Prof. Miethe, are entirely discordant with each other.

"It would be improper to assert, on the basis of these results alone, that Prof. Miethe's experiments have been proved to be definitely wrong. All that is proper to say is that a careful, competent and long, continued effort to confirm the German results has resulted in an entire failure to do so."

The *Scientific American* article politely suggested: "...one very vital possibility of mistake in experiments of this character lies in the accidental presence of a small impurity of gold in the mercury

employed... It is at least possible that such was the case... Perhaps it will be discovered that some minor and unnoticed detail in the arrangements or in the conduct of the experiment was really responsible for a successful transmutation in Prof. Miethe's case... We must confess, however, that we do not believe that this will prove to be the case. On the basis of all the evidence now available, including the experiments of Dr Sheldon and Mr Estey...it is our belief that a transmutation of mercury atoms into gold atoms does not occur and will not occur under the conditions which have been described by Prof. Miethe.

"It is to be freely admitted, of course, that a transmutation of mercury atoms into gold atoms is a theoretical possibility. The internal structures of the two atoms are similar. The removal of one unit of positive electric charge from the nucleus of a mercury atom, or the insertion of one additional electron into this atomic nucleus would result, it is believed, in the conversion of the mercury atom into an atom indistinguishable from the ordinary atoms of gold. Quite aside from the failure to confirm the results of Prof. Miethe, it remains entirely possible that one of these changes of atomic structure can be accomplished by some physical or chemical method yet to be discovered."

The scientists concluded with sardonic solemnity: "Gold can be extracted from mercury, but mercury cannot be transmuted into gold."

Sheldon and Estey reported elsewhere (*Phys. Review*): "The suggested explanation of a change of the number of electrons in the nucleus changing mercury to gold seems good in theory, but incredible in fact, for the potential drop per mean free path of an Hg molecule is only about 0.1 volt in these arcs."

Scientific American published another report, "More Mercuric Gold from Germany", in April 1926, announcing that a 10,000-fold increase in yield had been obtained in the production of mercuric gold. In his first experiments, Miethe found one part Au per 100 million parts Hg. The Siemens Works in Berlin bombarded Hg with electrons in extremely high vacuum, and obtained 100 mg Au from 1 kg of Hg. In June 1925, Siemens & Halske Akt.-Ges. registered its German Patent Specification (No. 243,670) for "Treating Hg" with spark discharges, cathode rays and canal rays. The difference of potential could be between 100–150,000 volts; capacitance was adjustable. Paraffin, ether or carbon tetrachloride were used as dielectrics.[29]

Other researchers were not so optimistic. Erich Tiede et al. reported: "The transmutation of Hg into Au is considered theoretically possible, but all experiments carried out under strict control of the original Hg proved to be failures. When the Hg, which was purified according to Miethe and Stammreich, was distilled in an all-glass apparatus similar to the one used by Bronsted and von Hevesey to separate the isotopes of Hg, it still showed up to 10^{-9}% Au. Optical detection is not sufficiently accurate, so they considered it necessary to melt the Au granule, which still held Hg, and weigh it on a microbalance.

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Milan Garrett (Clarendon Lab, Oxford) published completely negative results of his repeated attempts to reproduce the Hg-Au transmutation experiment by several methods. Garrett also attempted to prepare indium from tin and scandium from titanium by X-ray bombardment, also without success.

Erich Tiede et al. reported: "Hg distilled according to Miethe still had 0.3 mg Au per kg Hg. After two high-vacuum distillations, no more Au could be detected. With this preparation, the experiments of Miethe were repeated in several forms; no resultant Au formation was observed in any case." E. Duhme and A. Lotz confirmed this finding.

Duhme and Lotz also conducted numerous experiments with the initial cooperation of Miethe and Stammreich. They used very large arcs: 1.6 metres long, carrying 10 kW at 40 kV/800 amps per sq. cm through Hg vapour. Gold was found in some instances, such as when a sufficiently powerful current was passed between electrodes dipped in mercury, but those experiments were rejected because there had been too much contact with foreign metals. They found that Au will escape detection if certain impurities are present, producing an inhomogeneous distribution of Au which becomes detectable only after the arc treatment has coagulated it.

Prof. Fritz Haber et al. made careful attempts to repeat the work of Nagaoka and Miethe. Mercury in which no Au could be detected was subjected to six different treatments, but no Au was formed. In some cases Au was found, but only in amounts smaller than what could have come from the materials or from contamination. Nor could the yield be increased at will. The applied treatments were made with liquid and solid dielectrics with high-tension discharges, arcs in low, normal and high pressures, and high-vacuum electron bombardments.

The extraordinary sensitivity of their detection methods was exemplified by the instance of a co-worker who suddenly found traces of gold in some material he was analysing. No one else could detect Au in the other samples. It was found that the chemist habitually removed his gold-framed eyeglasses before making an observation. On this occasion, he had removed the glasses and then picked up a strip of ultra-pure lead to perform an analysis.

Another incident occurred when a lab worker was melting some Au. Soon afterwards, another worker in the next room found Au in material which previously had none in it.

The authors described their results as "proving merely that no method has yet

been published whereby analytically detectable amounts of Au can be formed in Hg".

Scientific American (April 1926) otherwise reported that at a "recent meeting" of the German Chemical Society, "Prof. Haber, who previously cherished the greatest doubt as to the accuracy of the experiments, congratulated Prof. Miethe and related...that he himself could confirm the results by repetition of the experiment". Haber apparently made the comment *before* he had completed his analyses of the electrodes, etc., and determined them to be the source of the Au.

Most of the criticism of Miethe's, Stammreich's and Nagaoka's experimental work focused on the questionable purity of the mercury they used. Their Hg had been purified by distillation and by dissolving it in nitric acid (1:4) and fusing the residue with borax (0.1 g). The resulting bead of Au, if any, was examined under the microscope. Usually they distilled the Hg twice, but in some cases as many as 15 times. Other researchers showed that no matter how carefully or often Hg was distilled, Au could be detected.

Miethe and Stammreich showed that the formation of Au from Hg depends on the application of intermittent electrical discharges. No gold forms when Hg is exposed to direct current. They also described an Hg turbine which allowed 2,000 breaks/minute with a potential of 110 volts; the current varied from 1 to 12 amps. The experiments showed a linear proportionality between the yield of Au and the product of wattage and time. The average yield of gold was 0.0004 mg/amp hour. The production of Au was facilitated by high pressure. When the discharge was passed between Hg poles in a paraffin dielectric, the gold was found dispersed along the line of discharge, but not in the Hg poles.[15]

The entire issue was never definitively resolved. Therefore, these experiments ought to be repeated with modern equipment and analytical techniques.

A. Gaschler attempted to reverse the Miethe-Nagaoka experiment by treating gold with high-speed hydrogen nuclei. He assumed that one of them might penetrate deeply into the electron shells of Au and be held by the innermost shells as a "paranucleus", forming a *Tiefenverbindung*. After 30 hours of bombardment, the spectrum of the tube began to show Hg lines which steadily increased in intensity. Gaschler postulated that Hg is a gold-hydrogen compound, similar to Manley's Hg halide.

The scientific community gave a fair and thorough review of the claims of Miethe, Stammreich and Nagaoka (who also skilfully managed the criticism). However, the entire issue was never definitively resolved. Therefore, these experiments ought to be repeated with modern equipment and analytical techniques. ∞

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